POWER MANAGEMENT SYSTEM

Field of the Invention

This invention relates to a portable power management system and method and has particular application for supplying power to a heater means at a controlled rate to enable emanation of a chemical formulation, such as insecticide or a fragrance. The invention also relates to a system and method of monitoring parameters of a heater means, to a computer program element and to a computer readable memory.

Background to the Invention

There are numerous patent documents that disclose systems for dispersing fragrance, insecticide or other volatile materials. For example in US Patent No 6,426,051 there is disclosed an oil burning lamp adapted to disperse fragrance which is made volatile from scented fuel. The prior art generally also includes candles that have wicks through which molten material is drawn by capillary action and where the molten material is derived from wax or a gel that may have a fragrance or insecticide impregnated therein.

United States Patent No 6,368,564 discloses a system for dispersing a fragrance incorporating a small electric motor and fan with the fragrance being impregnated in a gel-based aqueous reservoir. The fan, driven by the motor, disperses the fragrance from the surface of the reservoir to the atmosphere via small apertures in a housing. Similarly in European Patent No 0089214 there is disclosed a motor that is powered by a solar cell and drives a fan to disperse a fragrance from a reservoir. In US Patent No 6197263 there is disclosed an automobile air freshener that has a base power unit, for example a battery or cigarette lighter plug, and a detachable fragrance dispersing unit. The dispersing unit has a heating element adapted to receive replaceable gel-scent cartridges. The air freshener is attached to a vent system in the automobile to disperse the fragrance. Also in US Patent No 6,103,201 there is disclosed a propeller air freshener having a plastic rotor impregnated with fragrance, attachable to air vent louvres such that the air rotates the rotor to disperse the fragrance or scent. In US Patent No 5,038,972 there is disclosed an aerosol device that sprays fragrance in metered amounts. In US Patent No 6,085,026 there is an appliance having a base portion, the bottom of which is connected to an electrical power source. The base portion has a heating means and radiator means for heating and radiating a volatile substance kept in a container. The appliance is disposable and therefore used only once.

In US Patent No 5,574,821 there is disclosed a volatile substance dispenser that plugs into an electrical outlet to disseminate vapour into an area. The dispenser is discarded after the volatile substance is consumed. It uses a resistor heat pad screen and thermal conductor linked to a volatile material absorbent substrate in the dispenser.

Finally in US Applications 2002/0080330 A1 and US 2002/0081229 A1, there is disclosed a scent storage device which is inserted into a scent delivery device and used with a computer system. The scent storage device has a number of scent channels and include a scent material and a scent activation system electrically connected to the scent delivery device. The scent material includes a number of individual event portions and the activation system selectively activates and consumes individual event portions as needed. The scent activation system includes a series of resistors with one resistor for each event portion. A pulse causes a first resistor in the resistor array to heat up and vaporise the material in the associated event portion which releases the scent material. The pulse causes the resistor itself to vaporise thereby disconnecting the event portion from the circuit and then causing the next resistor in the series to be connected to the circuit. Thus the resistors are destroyed after each electrical pulse is applied to release the scent and is therefore not reusable.

Collectively all of the above documents do not allow a controlled amount of fragrance or insecticide to be released. They are generally cumbersome including motors and fans and in some instances are not reusable. Some of the prior art require particular units to be attached to other devices such as air vents in vehicles in order to disperse the volatile material.

The present invention seeks to overcome these disadvantages by providing a power management system that controls the amount of power to be delivered to a heater means , preferably in the form of a microheater element, to disperse a fragrance or insecticide in controlled amounts. It is intended to be reusable in the sense that a scent or insecticide reservoir can be refilled or replaced as many times as needed.

<u>Summary of the Invention</u>

According to a first aspect of the invention there is provided a portable power management system for providing power to a heater means in order to vapourize a chemical formulation into surrounding atmosphere, the system comprising:

pulse generation means for supplying energy pulses;

switch means connected to the pulse generation means and to the heater means, the switch means receiving the energy pulses from the pulse generation means;

the switch means further delivering to the heater means amplified energy pulses at a rate controlled by the pulse generation means in order to sufficiently heat the heater means to vapourize the chemical formulation;

wherein an initial pulse delivered to the heater means has a first portion and a second portion, the first portion having more energy than the second portion so that a predetermined temperature of the heater means is attained by delivery of the first portion and the temperature is substantially maintained by delivery of the second portion.

The system may further comprise processing means, in the form of a microcontroller, to control the pulse generation means and thereby control the frequency of pulses delivered to the switch means. The microcontroller may also control or vary the number of pulses delivered from the pulse generation means to the switch means over a preset period of time.

The pulse generation means is preferably a pulse width modulator. The pulse generation means may set the pulse width of the pulses and therefore set the duty cycle of the pulse waveform. The system is preferably powered by one or more batteries. The system preferably comprises battery voltage sensing means to sense the battery voltage and indicate the relative charge in the battery or batteries.

The system may further comprise heater voltage sensing means for recording the voltage across the heater means and current sensing means for recording current through the heater means.

Thus the system may deliver to the heater means a substantially constant energy per pulse (or group of pulses) even while the battery voltage is falling to enable relatively constant performance to result. Different power maps may used depending on the specific chemical formulation used, e.g. for an insecticide or fragrance, in order to minimise heat loss. For example the pulse repetition rate may be increased or decreased or the number of pulses delivered per cycle may be varied.

The system is preferably linked to a heater indication means to indicate to a user the state of the heater means.

Preferably the heater means is a microheater element, the microheater element preferably being an impedance means and more particularly a resistor. Preferably the microheater element is mounted separately to the power management system. The switch means may be transistor means and more particularly one or more field effect transistors.

According to a second aspect of the invention there is provided a method of providing power to a heater means in order to vapourize a chemical formulation into surrounding atmosphere, the method comprising the steps of:

generating energy pulses to be received by switch means;

delivering amplified energy pulses from the switch means to the heater means at a controlled rate in order to heat the heater means to vapourize the chemical formulation;

wherein an initial pulse delivered to the heater means has a first portion and a second portion, the first portion having more energy than the second portion so that a predetermined temperature of the heater means is attained by delivery of the first portion and the temperature is substantially maintained by delivery of the second portion.

The method may further comprise the step of varying the number of pulses received by the heater means over a preset period of time.

The method may further comprise the step of controlling the width of the current pulses and therefore the amount of energy delivered to the heater means.

The pulses may be generated by a pulse width modulator under the control of a processing means, in the form of a microcontroller. The frequency of the pulses may be controlled by a switch means.

The method may further comprise the step of sensing battery voltage, where power is supplied by one or more batteries, and indicating the relative charge in the battery or batteries.

The method may further comprise the step of indicating the state of the heater means to a user.

According to a third aspect of the invention there is provided a system for monitoring parameters of a heater means where the heater means is supplied with energy pulses in order to vapourize a chemical formulation into surrounding atmosphere, the system comprising:

computer processing means;

power controller means for controlling delivery of the energy pulses to the heater means and for receiving data on the parameters;

wherein the computer processing means is linked to the power controller means such that the parameter data is able to be transmitted to the computer processing means for analysis and an initial pulse delivered to the heater means has a first portion and a second portion, the first portion having more energy than the second portion so that a predetermined temperature of the heater means is attained by

delivery of the first portion and the temperature is substantially maintained by delivery of the second portion.

The parameters of the heater means to be monitored may include voltage, current or temperature and the data may include magnitudes of voltage, current or temperature over a period of time.

The system may further comprise voltage sensing means for recording the voltage across the heater means. The system may further comprise current sensing means for recording the current through the heater means. The system may further comprise temperature sensing means for recording the temperature of the heater means.

Power may be delivered to the heater means via one or more batteries. The system may further comprise battery voltage sensing means to sense the voltage of the battery or batteries.

The computer processing means may transmit commands to the power controller means. The commands may include a start command to start supply of power to the heater means and a stop command to cease such supply of power to the heater means.

The start command may include a digital value representative of the duration of an energy pulse (ON TIME) in a period of time to be delivered to the heater means upon which the power controller means implements the delivered energy pulse duration. The stop command may also include a digital value representative of the duration of no energy pulses (OFF TIME) in the period of time to be delivered to the heater means by the power controller means.

The start command may also include a data log rate indicative of the number of transmissions of parameter data from the power controller means to the computer processing means in a period of time. Preferably the data log rate is between zero and 20Hz.

According to a fourth aspect of the invention there is provided a method of monitoring parameters of a heater means where the heater means is supplied with energy pulses in order to vapourize a chemical formulation into surrounding atmosphere, the method comprising the steps of:

controlling delivery of the energy pulses to the heater means;

measuring and recording data on the parameters; and

transmitting the parameter data to a computer processing means for further analysis;

wherein an initial pulse delivered to the heater means has a first portion and a second portion, the first portion having more energy than the second portion so that a predetermined temperature of the heater means is attained by delivery of the first portion and the temperature is substantially maintained by delivery of the second portion.

According to a fifth aspect of the invention there is provided a computer program element comprising computer program code means to control a processing means to execute a procedure for monitoring parameters of a heater means where the heater means is supplied with energy pulses in order to vapourize a chemical formulation into surrounding atmosphere by:

controlling delivery of the energy pulses to the heater means;

measuring and recording data on the parameters; and

transmitting the parameter data to a computer processing means for further analysis;

wherein an initial pulse delivered to the heater means has a first portion and a second portion, the first portion having more energy than the second portion so that a predetermined temperature of the heater means is attained by delivery of the first portion and the temperature is substantially maintained by delivery of the second portion.

According to a sixth aspect of the invention there is provided a computer readable memory encoded with data representing a computer program for directing a processing means to execute a procedure for monitoring parameters of a heater means where the heater means is supplied with energy pulses in order to vapourize a chemical formulation into surrounding atmosphere by:

controlling delivery of the energy pulses to the heater means;

measuring and recording data on the parameters; and

transmitting the parameter data to a computer processing means for further analysis;

wherein an initial pulse delivered to the heater means has a first portion and a second portion, the first portion having more energy than the second portion so that a predetermined temperature of the heater means is attained by delivery of the first portion and the temperature is substantially maintained by delivery of the second portion.

According to a seventh aspect of the invention there is provided a computer program element comprising computer program code means to control a processing

means to execute a procedure for providing power to a heater means in order to vapourize a chemical formulation into surrounding atmosphere by:

controlling the generation of energy pulses to be received by the heater means in order to heat the heater means to vapourize the chemical formulation; and

controlling the frequency of generated pulses received by heater means;

wherein an initial pulse delivered to the heater means has a first portion and a second portion, the first portion having more energy than the second portion so that a predetermined temperature of the heater means is attained by delivery of the first portion and the temperature is substantially maintained by delivery of the second portion.

Brief Description of the Drawings

Preferred embodiments of the invention will hereinafter be described, by way of example only, with reference to the accompanying drawings wherein:

Figure 1 is a schematic block diagram of a power management system according to the invention;

Figure 2 is a detailed circuit diagram of the power management system; and

Figure 3 is a schematic diagram showing mounting of heater means in the form of microheater elements.

Figure 4 shows comparative plots of energy efficiency of a square pulse and a stepped pulse;

Figure 5 shows a plot of mass delivery rate of a chemical formulation for a particular configuration of the system;

Figure 6 shows a plot of battery rundown under a given set of conditions; and

Figure 7 shows a set of graphs of the efficacy of a particular micro device using the system.

Detailed Description of Preferred Embodiments

With reference to Figure 1 there is shown a block diagram of various components pertaining to a power management system for a portable battery powered device used to emanate a volatile chemical formulation, such as a fragrance or insecticide. It comprises a power management module 10 which includes a processing means in the form of a micro-controller 12, switching means 14, voltage sensing means 16 and interface 18. Each of the switching means 14, voltage sensing means 16 and interface 18 are linked to the micro-controller 12 which is also linked to a controls unit 20. A heater means, in the form of a microheater element 22, is

connected to the switching means 14, heater indication means 24 and to battery 26. Other heater means such as as coils or circuit elements may be used. The battery 26 is also linked to a battery indicator means 28 in indicators module 30. The battery 26 also supplies power to the controls unit 20, voltage sensing means 16 and switching means 14. Optionally there is provided a computer processing means 33 in the form of a PC that is linked to the micro-controller 12 through the interface 18 for the purpose of monitoring parameters of the microheater element 22. The microheater element 22, preferably in the form of an impedance means such as a resistor and more particularly a surface mounted resistor, is made to heat up via the supply of current from battery 26 in order to vaporise an oil-based solution into the atmosphere through contact with a wick arrangement that has absorbed the solution. The current is pulsed via the operation of pulse generation means, such as a pulse width modulator, in the micro-controller 12 and through switching means 14. Thus the switching means 14 is controlled by the micro-controller 12 to deliver a pulse having a certain duty cycle in order to preserve the battery voltage. Alternative power maps may be utilised to be described hereinafter.

Shown in Figure 2 is a detailed circuit diagram of the system of Figure 1. The microheater element 22, in the form of an impedance such as a surface mounted resistor, is ideally mounted in a small package that can be driven to a high temperature with minimal amount of energy. It has sufficiently low resistance to allow substantially high power dissipation when connected to a small number of batteries such that a high enough temperature for emanation is reached. The resistance will generally be in the range of about 2 ohms to 10 ohms to allow approximately 600mW dissipation from 3-6 volt batteries. It also accommodates situations where the battery voltage is low, such as 1.5-2.0 volts. The resistance is chosen such that power losses in other resistive components in the circuit, such as the battery internal resistance, switches and other circuitry are negligible compared to the power dissipated in the resistor 22. The resistor 22 is of a sufficiently small size that it is effectively heated with a small current while being large enough to heat enough surface of the attached wick for material emanation. In view of this an 0402 package may be suitable for pest control applications but other applications may be more efficient with lower temperatures and larger surface area. The resistor package sizes may come in small or 63mW (0402 and 0603), medium size or 125mW (0805) and 250mW (1206) and a large size or 500mW (2010) and 1000mW (2512).

The surface mounted resistor 22 may be incorporated in a plugable module located on the power management module 10 circuit board. An example of the

plugable module is shown at 32 in Figure 2. Up to two resistors may be inserted into the module 32 at any one time. An example of the module 32 with its pin arrangement is shown in Figure 3. More particularly there is a 5 x 2 pin array 34 that enables resistor R1 36 and resistor R2 38 to be inserted therein. The dark pin circles indicate the active connection, that is resistor R2 is active. The end pins are used to connect to an indicator or LED unit 40 to verify the correct connector placement or orientation. If the resistor is rotated 180° then R1 resistor becomes the active resistor. The indicators 40 may use the green LED to indicate that the resistor is correctly fitted or the red LED to indicate that it is incorrectly fitted. Power is optionally supplied for either via the battery 26 or via VCC for situations where the module is plugged into a mains supply, in other words fixed in a designated area such as a room, in order to save on battery power. The size of the module 32 to house the resistors will be such that it can support in combination with the power management module 10, dispersion devices up to 72 x 36mm in size. Many modules 32 can be fitted onto a standard prototype PCB panel. This quantity will depend on the module size. The microheater elements or resistors 22 are able to withstand temperatures up to 150°C except for the 0402 and the 2512 models which are rated at 125°C.

At the core of the invention is a micro-controller 12 that has connections to various parts of the overall circuit. In particular it has a pulse generator, in the form of a pulse width modulator connected at pin 13 which is linked to switching means 14 in the form of an n-channel field effect transistor. The output of the switch 14 is in turn linked to the module 32 supporting the surface mounted resistor 22. The battery voltage is detected on pin 2 via operational amplifier 42 which may have a gain of about 0.43. The current passing through the load resistor 22 is able to be sensed on pin 3 which results from a load current sensor in the form of a resistor 44, rated at 51M ohms which feeds into a further operational amplifier 46 set to a gain of about 50. This amplifies the current up to about 2 amperes and is then input to the micro-controller 12. From the current and resistor values, the voltage across the resistor 22 can be determined. The temperature of the surface mounted resistor in module 32 may be sensed on pin 4 via a negative temperature co-efficient thermistor 48 which is input to a further operational amplifier 50. The thermistor may be physically connected to the resistor 22 via a cable or otherwise automatically in order to measure its temperature and forward that measurement to the micro-controller 12. A trimpot 52 may also be used for initial testing which is input to the micro-controller 12 on pin 5. A quartz crystal oscillator rated at up to 20MHz is connected between pins 9 and 10 of the micro-controller. On pin 14 there is an indicator in the form of a LED 54

which is used to show that power is presently being applied to the load or the surface mounted resistor 22. The micro-controller 12 is preferably a PIC16F876 model with analog to digital converters, timers, memory and a UART. A power supply 56 provides an accurate five volt output as a reference for use by the analog to digital converters in the micro-controller 12. It is indicated as being on by the LED 58.

The switch 14 is preferably an n-channel power FET rated at approximately 50 milliohms ON resistance. It is used in conjunction with a ten bit pulse width modulator in the micro-controller 12 to be able to accurately control the rate of energy delivered to the load resistor 22. Therefore the minimum value or base time rate for the pulse width modulator will be set to approximately ten microseconds which means that the full period of the cycle will be approximately 10.24ms with the ON time being increased from 0 to 10.24ms in 10 micro-second increments, as a result of there being 1024 possible values. The switch 14 essentially distributes a series of amplified current pulses having a magnitude that enables the resistor 22 to heat sufficiently, typically 0.5 amperes. The pulse width modulator is not able to supply current pulses of this magnitude directly to the resistor 22. The switch 14 operates in accordance with the signals received at its gate input from the pulse width modulator as above, including the actual pulses delivered from the pulse width modulator. The switch 14 either provides an open circuit or closed circuit condition permitting current flow through the resistor 22 in accordance with the received signal from the pulse width modulator.

Ideally one pulse per 100 seconds will be available to provide power to the surface mounted resistor 22. However when first turned on, the device should be under a heavy load for a brief period in order to produce a burst of insecticide vapour or fragrance so consumers experience an immediate effect. That is they do not have to wait some time before the vapour concentration reaches its effective level. The device therefore will then produce perhaps one pulse per ten seconds for the first one or two minutes before dropping back to the maintenance level of one pulse per 100 seconds. The consumer may have control over this in order to boost the effect of providing bursts of vapour by using a control switch 21 to enable them to turn the unit off and on and also switch it to a high burst mode. The power management module must draw minimal power, for example 600mW for each one second ON time and 99 seconds OFF cycle yielding an average power consumption of 6mW per second. Ideally the power drawn by the rest of the circuit should not be more than one tenth of this, or be less than 600 microwatts or having a circuit impedance of approximately 10K ohms.

With the preferred battery configurations of two standard AA batteries the device should be able to run for three months in field use based on an 8 hours use per night and therefore 720 hours service on an appropriate duty cycle such as mentioned previously with one pulse of one second duration per 100 seconds. The number of batteries may be extended to three AA batteries or 4 AAA batteries. The power management circuit is able to drive the surface mounted resistor 22 at a substantially constant power even while battery voltages are dropping hence the requirement of a battery voltage sensor 16 and current sensor 44 of the load whilst the pulse is delivered to the load. This requires some compensation for the proportion of the greater fraction of power that will be lost due to circuit components and battery as the voltage drops.

As alluded to earlier different power maps may be used depending on the specific formulation used, such as insecticide or fragrance, and that minimises heat loss. For example, power may be needed to be varied in pulse number to achieve the greatest efficiency, such as a two step high-low power map which essentially is two rapid pulses close to each other within one cycle. At some point the battery voltage will drop below the minimum required to dissipate the 600mW of power to the resistor. Acceptable insecticidal performance may still be possible by increasing the pulse repetition rate say to one every fifty seconds. Hence the pulse frequency may require change.

In the following few paragraphs a thermal model for thermofoil and surface mount resistor heaters is provided. This is to enable prediction of the temperature of a small battery power heater with a simple physical model. It is also provided to characterise the heater behaviour with a small number of physical constants and to provide a method of measuring these constants and to compare different heaters.

A simple energy balance is assumed in which the heater temperature is determined by the electrical energy provided to the heater and the loss by thermal diffusion. Details as to the thermal defusion are presently ignored and the heater is modelled, in its mount, with any thermocouple or active wick as a single element with a heat capacity c[J/K] which dissipates heat according to Newton's Law with a thermal transport coefficient a[J/K/s].

The heat capacity c and thermal transport coefficient a describe the heater completely. The measurements of these two heater constants allow direct comparison of different heaters, temperature predictions and are the variables for optimisation during further development.

The energy content of the heater q[J] is given by the energy balance equation

$$\frac{\partial q}{\partial t} = \frac{V^2}{R} - a(T - T_0) \qquad (1)$$

where the first term to the right of the equal sign is the power delivered by the battery and the second term is the heat loss due to thermal diffusion. T and T_0 are the heater temperature and ambient temperature respectively. The heat and temperature are connected by the heat capacity equation

$$q = cT \qquad (2)$$

so that the differential equation is

$$\frac{\partial T}{\partial t} = \frac{V^2}{cR} - \frac{a}{c}(T - T_0) \qquad (3)$$

If the voltage is constant or the power is not in any other way varied through the pulse, the solution is

$$T = \frac{V^2}{aR}\left(1 - \exp\left(-\frac{a}{c}t\right)\right) + T_0 \qquad (4)$$

A variable voltage will likely require numerical integration. For batteries driving low resistances an initial rapid voltage drop is likely to occur. If this can be ignored this result allows measurement of the heat capacity and transport coefficient, as well as providing the time dependent temperature.

Fitting equation (4) to temperature data obtained from a 5.5 ohm thermofoil heater taped to a PC board, driven by batteries reading 2.8V open circuit but dropping immediately to 2.6V when driving a load gives a heat capacity c of 0.43 J/K and a thermal transport coefficient of 0.0233J/K/s. The poor match on the initial point is probably due to a break down of the model assumption of a single thermal mass at short times, where the heater and PC board probably should be treated separately. A

plot of the temperature in Celsius versus time in seconds of the warm-up period for a thermofoil reveals that it takes about 60 seconds to reach a thermofoil heater temperature of about 90°C.

In analysing the model above, it can be determined how long the heater takes to warm up to a given temperature. By rearranging equation (4) for the warmup time the following equation results:

$$t = -\frac{c}{a}\lambda n\left(1-\frac{aR}{V^2}(T-T_0)\right) \tag{5}$$

Instructively, the first terms in the series expansion are

$$t \approx \frac{cR}{V^2}(T-T_0)+\frac{acR^2}{V^4}(T-T_0)^2+\ldots. \tag{6}$$

The first term is the time taken for the resistor to heat up if there was no thermal dissipation at all. Thermal dissipation, as indicated by the coefficient a, occurs in the higher order terms. Thermal dissipation is lost energy and therefore the higher order terms need to be avoided. An efficient warm-up will occur if the second order term is negligible which is the case if

$$\frac{V^2}{aR} >> T-T_0 \tag{7}$$

This condition defines the efficient warm-up regime.

The maximum temperature can be determined by setting T = ∞ in equation (4). The maximum temperature is given by the following equation

$$T_{\max} = \frac{V^2}{aR}+T_0 \tag{8}$$

By restating equation (7) the most efficient warm-up regime is when conditions give

$$T \ll T_{max}. \qquad (9)$$

In other words, the most efficient warm-up occurs when the system is designed with a large "thermal headroom", that is when operating well below the maxmum temperature.

A determination as to how much energy it takes to warm up the heater to a given temperature can be made. If it takes t seconds to achieve a given temperature, from equation (5) the energy required will be

$$Q = -\frac{cV^2}{aR} \ln\left(1 - \frac{aR}{V^2}(T - T_0)\right) \qquad (10)$$

Q increases asymptotically as the maximum temperature is approached. Using the experimental example, the energy required to reach a maximum temperature of 100°C in the warm-up phase is about 120 Joules. Temperatures that approach the maximum temperature of 100°C are wasteful as the amount of energy used increases asymptotically as they near the 100°C temperature.

A plot of the energy to achieve 70°C in the warm-up phase as a function of voltage, with reference to equation (10), provides that a higher voltage results in a reduced energy consumption up to a point. As the voltage increases, the energy required approaches a minimum of

$$Q = c(T - T_0)$$

This is just the energy required to heat the resistor without loss and the first term in the expansion of equation (10).

The power that is required to maintain a given temperature may also be determined. Having achieved the target temperature in the initial warm-up phase, the power consumption can be dropped to a maintenance level and the applied voltage correspondingly dropped. The power requirement is given by the steady state condition

$$\frac{\partial T}{\partial t} = \frac{V^2}{cR} - \frac{a}{c}(T - T_0) = 0$$

(11)

$$P = \frac{V^2}{R} = a(T - T_0)$$

(12)

In the experimental example, the 2.2 V is required to maintain 70°C. This amounts to approximately 70% of the power used in the warm-up phase.

A determination as to the total energy consumed in a given pulse can also be made. If a temperature of T is required to be held for τ seconds the most efficient way to achieve this is to drive at the maximum power through the initial transient and then modify the voltage or duty cycle to drop the power to the maintenance level for the stipulated time. The energy consumption is then given by the following equation

$$Q = -\frac{cV^2}{aR}\lambda n\left(1 - \frac{aR}{V^2}(T - T_0)\right) + a(T - T_0)\tau$$

(13)

Surface mounted NTC resistors will be used to measure some of the thermal characteristics for the different resistor package sizes. The resistance of these components is given by the equation

$$R = A\exp(\beta/T) \qquad (14)$$

where β will be stated by the manufacturer. The parameter A is then found by a resistance measurement at a single temperature.

Driving a mounted resistor with a stable voltage will eventually result in a steady state temperature. Despite differences in the time dependence of approach to equilibrium, the equilibrium temperature will still be

$$T_{\max} = \frac{V^2}{aR} + T_0 \qquad (8)$$

This will allow an estimation of a. This will most likely be a fair estimate of a for the non-surface mount heating resistors in the same package size.

An estimation of c for these components is somewhat more difficult as there is no simple equation to relate c to a single measurement. Instead, it must be determined as a fitting parameter for the temperature-time curve.

The temperature of the NTC resistor is given by the earlier result except that R changes with temperature according to equation (14).

$$\frac{\partial T}{\partial t} = \frac{V^2 \exp(-\beta / T)}{Ac} - \frac{a}{c}(T - T_0) \qquad (15)$$

There is no analytical solution for the resulting differential equation, so it must be solved numerically, for instance by using the finite difference scheme

$$\Delta T = c^{-1}\left[\frac{V^2}{R}\exp\left(-\beta T^{-1}\right) - a(T - T_0)\right]\Delta t \qquad (16)$$

Fitting the numerical solution of the differential equation to experiment using this result will give an estimate of c for the NTC component. This value of c is expected to be similar to the fixed resistors in the same package size, but not necessarily the same, as the construction and materials will not be identical. For a rough estimate of the dynamics of approach to the steady state temperature it will probably be adequate. If the steady state temperature is the quantity of interest, then not knowing c exactly will not be that important.

Thus the most efficient driving scheme identified during this thermal analysis has resulted in equation (13). Ideally a 2-step pulse is implemented in which the heater is driven at the maximum available power until the target temperature is reached. After this the power is reduced to a maintenance rate. The maintenance

power level is adapted to the drop on battery voltage but the duration of the maximum power step is adapted to the battery voltage.

This is clearly shown in Figure 4 where in the first plot of temperature versus time a square pulse with a target temperature of 100°C is used whereby 655 millijoules per pulse is used. In the second plot of Figure 4 of temperature versus time a stepped pulse is used with the same target temperature at an energy cost of 485 millijoules per pulse. Thus a 25% energy saving is made with the temperature being maintained for a longer period of time. This is due to 750 milliwatts of power being used in the first half a second and then this is dropped down to 225 milliwatts in the next half second.

Figure 5 shows a plot of the refill mass in grams against time in minutes or the mass delivery rate which ends up being 160 micrograms per hour. An 80 micro millimeter wick was used with two AA batteries rated at 3 volts with on time of 0.3 seconds, a pulse width of 1.7 seconds delivered every 60 seconds.

In Figure 6 there is shown a plot of the battery run down with battery voltage underload plotted against time in seconds. It can be seen that two AA batteries give a one to two month performance at 50 micrograms per hour delivery rate.

Figure 7 shows the required efficacy of a micro device using two AA batteries rated at 3 volts with the number of bites and landings shown plotted against the nominal active release rate in micrograms per hour. 50 micrograms per hour is equivalent to one two-second pulse emitted every three minutes and twelve seconds and it is noted a 90% bite inhibition is reached in fifteen minutes.

In order to provide increased power to cater for the drop off in voltage a particular microcontroller is chosen that performs this task at voltage and then drops off the rate at which pulses are provided to the heater. The microcontroller is a Fairchild ACE1101L and is an 8 bit, 8 pin flash based microcontroller specified down to 1.8V over a temperature range. The microcontroller has a low voltage brown out reset of 1.8V which can be used as a low battery detection. It also has a characteristic that its internal oscillator slows markedly for voltages below 2.2V, that is, it would compensate for low battery voltage. The internal oscillator is used for both ON and OFF times.

As mentioned previously in the indicators module 30 there is a heater indicator 24 which may be used to provide an indication to the user where for instance the resistor 22 burns out, for example by the light not turning off if a high resistance is sensed. The indicator could be a LED or a buzzer or the indication scheme could be analogous to car indicator lights, for example, a correct device operation as indicated

by on for several seconds then off when the device is first turned on, failure to light means battery failure and failure to go off means device or resistor failure. A battery low indicator 28 or alternatively a battery OK indicator may be used. The battery OK indicator may be instituted by an LED turning on for some seconds, then off, or beeping if the battery is good. All of these indicators are necessary as the effect of the product is invisible in terms of the fragrance or insecticide being released and, as it is also inaudible the only indication of a flat battery or a blown microheater element will mean that the consumer suffers bites or is not aware of any fragrance.

As mentioned previously the power management module 10 has an interface 18 linked to a computer processing means 33, in the form of a PC. The link 60 between interface 18 and PC 33 is a serial link and enables the monitoring and logging of load current, load voltage, battery source voltage and load temperature to be transmitted from the micro-controller 12 to the PC 33. The interface 18 primarily comprises a connector 62 which is a DB9 female connector having 9 pins which is wired as a modem for one to one connection to a standard PC serial port. The interface 18 also includes an RS232 driver circuit 64 which has two transmit pins and two receive pins connected to the connector 62 and also to respective pins in the micro-controller 12 in order to transmit and receive the various signals representative of current, voltage and temperature. Other properties or measurements that need to be conducted in respect of the microheater element 22 may also be transmitted to the PC 33.

The serial link 60 is preferably a RS-232, 19.2Kbaud, 8 bit, no parity with one stop bit transmission characteristics. It is specifically connected to the connector 62 and to the PC serial port. A simple protocol may be implemented and in particular control commands may be transmitted from the PC 33 which include stop and start commands. When a start command is received by the micro-controller 12 the following values are also sent:

ON time in tenths of seconds with the minimum being zero and maximum being 65,535;

OFF time in tenths of seconds with the minimum being 0 up to a maximum of 65,535 pertaining to a ten bit representation;

Total test time in seconds, with the minimum being 0 up to a maximum of 65,534 or forever until manually stopped;

Percentage pulse width during the ON time with a minimum being 0 and maximum 100; and

Data logging rate, being the rate by which data is sent back to the PC 33 being a minimum or 0Hz and a maximum of 20Hz, thus allowing for up to 20 separate measurements to be transmitted per second.

The logging data that is sent from the micro-controller 12 to the PC 33 is in the format whereby time stamps are in seconds from the start of a test, load current, load or battery voltage, thermistor temperature.

Software in the micro-controller 12 performs various functions including driving the serial link 60, controlling the switch 14, which in turn provides power to the load, via the stop and start commands from the PC 33, and reads, logs and sends data for current, voltage and temperature measurements. The micro-controller 12 has up to 5 off 10 bit analog to digital channels at its disposal, however for practical purposes to simplify data handling and to speed up conversion time to around 20 micro-seconds per sample, only three off channels in an 8 bit mode will be used.

As mentioned previously the load voltage of the microheater element 22 is measured from the source or battery voltage with operational amplifier 42 having a gain set at 0.3. This allows source voltage measurements of up to 16.7V. The extra voltage drop from the current sensor resistor 44 is subtracted from this to give the figure for the load voltage across resistor 22. This data is then time stamped and sent to the PC33 over serial link 60. Temperature will be read from the negative temperature co-efficient glass bead thermistor 48 which gives a value from a resistor divider driving an operational amplifier 50. This value is then converted to a temperature.

Software stored in a memory on the PC33, known as CALS or control and logging software undertakes the two commands previously mentioned which it sends to the power management module 10 and more specifically to the micro-controller 12. The software may be written in visual basic to run on a Windows 2000 platform. The software updates the display of the PC33 to show the latest logging data as it arrives from the micro-controller 12. The CALS user interface will have dialog boxes allowing editing of all user variables with a reference to the control commands. A dialog box will be provided to giving a file name for the logged data, such as current, load or battery voltage and temperature, to be stored in PC33 memory. This may be automated to use data and time as a file name if preferred. The file will be opened and continually updated until logging finishes and as a result is not available until the testing has finished. However data will be made accessible during the course of an experiment or test and be written out to a copy file. Furthermore a plot of a voltage time characteristic, or even the voltage as a number can also be shown. Furthermore

the logged data may be, delimited text values with a new line for each reading to allow an easy importation to a spread sheet under the control of the PC software.

Data may also be uploaded or transmitted from the PC33 to the micro-controller 12, of which the start and stop commands are examples

It is to be noted that this device can potentially be used for air fresheners and many other applications. As fragrances have a lower vaporisation temperature than insecticides, an air freshener device would probably operate at a lower power requirement. The circuit design will therefore allow for different power maps with selection between maps being possible at the time of manufacture, for example by the presence or absence of a 0 ohm link or similar method to designate the device as pest, air or other application. A heater of different resistance or package size might also be chosen at manufacturing time if necessary.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive.